# Lunar Surface Charging in the Earth's Distant Magnetotail


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# Motivation and Objectives

**Characterize and understand the near-lunar plasma environment in the Earth's distant magnetotail, and the effect on the electric charging of the Moon's surface.**

In particular, determine what plasma conditions, and properties of the lunar regolith, would be required to produce **the extreme positive charging of the lunar dayside in the tail lobes**, as ***possibly*** inferred from:

- **Apollo CPLEE electron measurements from the lunar surface [Reasoner and Burke, 1972].**
- **Ions of lunar origin detected by Kaguya in orbit [Tanaka et al., 2009].**

# The Lunar Plasma Environment

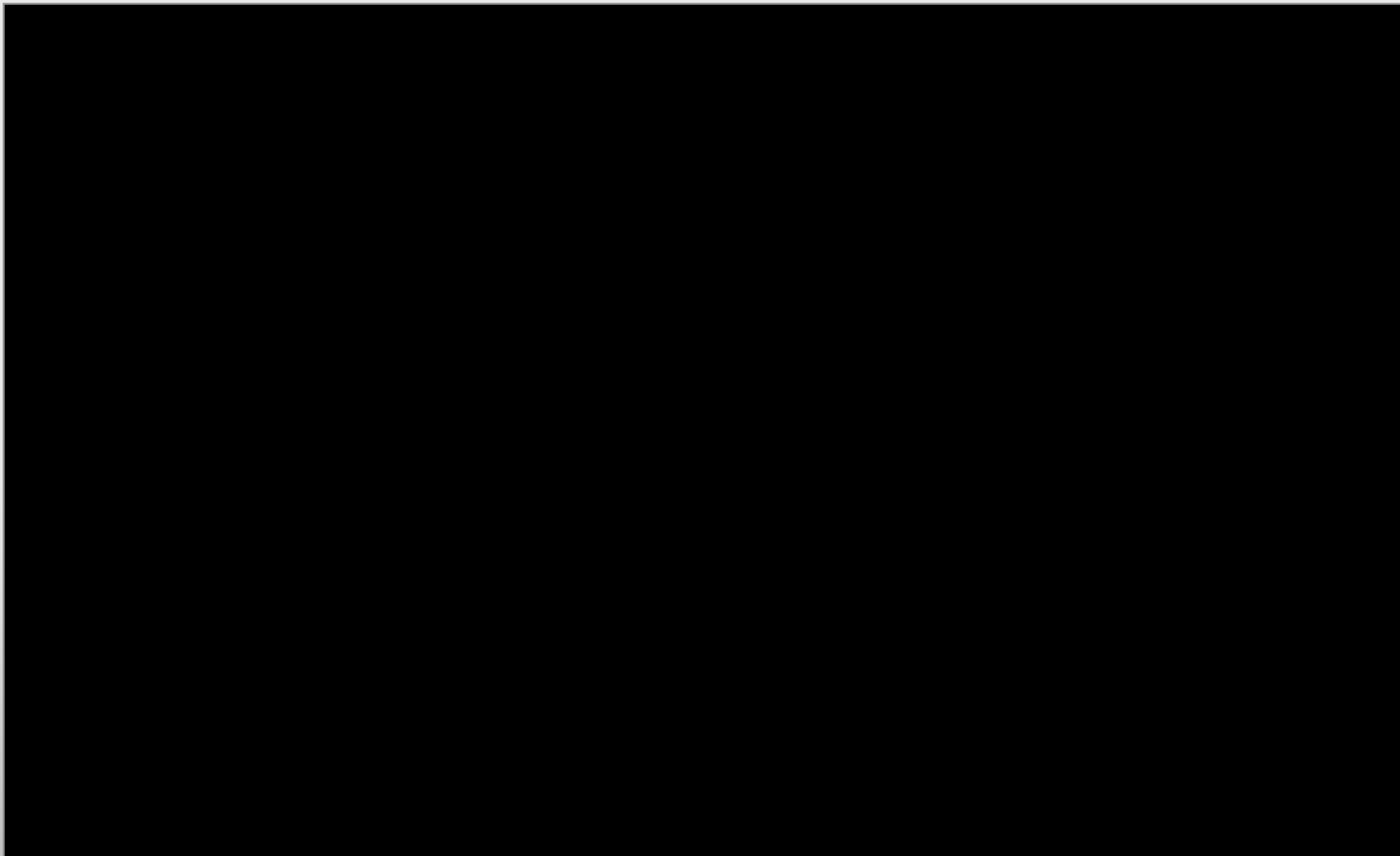
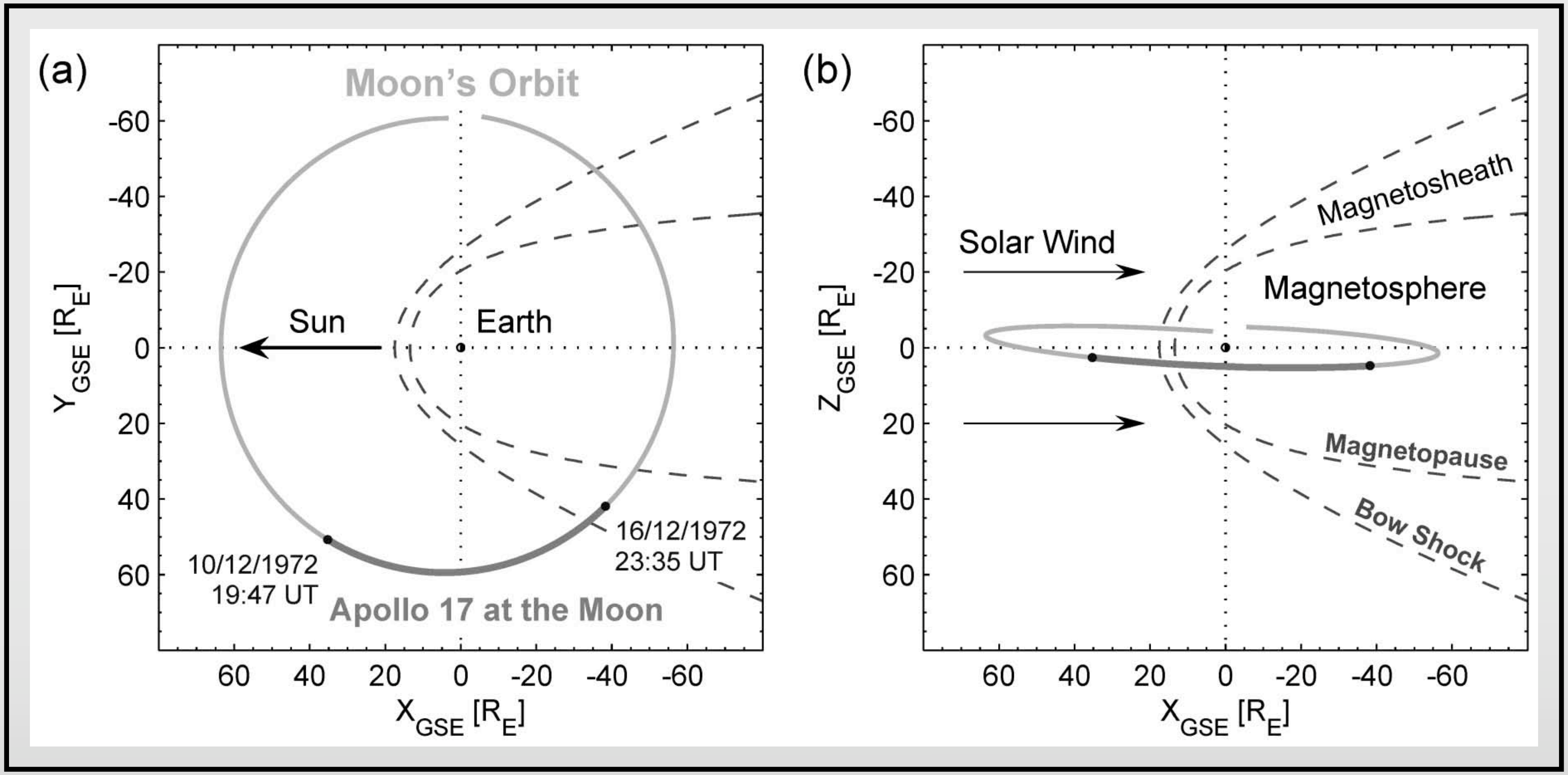


Figure from “Heliophysics Science and the Moon” report from the NAC

# The Moon in the Magnetotail




**Orbit of the Moon during the Apollo 17 mission** with predictions for *typical* magnetopause and bow shock locations.

**The Moon is ≈70% in the solar wind, ≈20% in the magnetotail, and ≈10% in the magnetosheath.**

Apollo missions did not experience the Moon in the magnetotail!

# A Comparison Between Lunar Surface Charging in the Solar Wind and Magnetotail

Typical plasma conditions – ISEE-3 electron data [Slavin et al., 1985].

| Condition | $n$ [cm$^{-3}$] | $T_e$ [eV (K)] | $T_i$ [eV (K)] | $V$ [km s$^{-1}$] |
|---|---|---|---|---|
| Slow solar wind | 10 | 12.1 ($1.4 \times 10^5$) | 8.6 ($1.0 \times 10^5$) | $-400$ |
| Tail lobes | 0.02 | 86 ($1.0 \times 10^6$) | 86 ($1.0 \times 10^6$) * | $-170$ |
| Plasma sheet | 0.2 | 216 ($2.5 \times 10^6$) | 1577 ($1.83 \times 10^7$) # | $-100$ |

Assumptions: * $T_i = T_e$ and # $T_i = 7.3 T_e$.

| Condition | Dayside $\phi_S$ | Nightside $\phi_S$ | Electron current $J_{e0}$ |
|---|---|---|---|
| Slow solar wind | ~ +4 V | ~ $-50$ V | ~ 1.0 μA m$^{-2}$ |
| Tail lobes | ~ +10 V | ~ $-325$ V | ~ $10^{-2}$ μA m$^{-2}$ |
| Plasma sheet | ~ +6 V | ~ $-600$ V | ~ $10^{-1}$ μA m$^{-2}$ |

**Dayside** – photoemission dominates plasma electron currents

**Nightside** – plasma electron currents (Temperature) dominate.

# Evidence for Extreme Positive Charging on the Lunar Dayside in the Tail Lobes

Reasoner and Burke [1972] suggested that Apollo 14 CPLEE detected photoelectrons with energies of up to 200 eV.

**It was argued that this was evidence for surface potentials of at least 200 V positive**.

Tanaka et al. [2009] reported that Kaguya PACE-IMA detected ions of lunar origin with energies of up to 400 eV.

Since the spacecraft was probably charged ~40 V positive, this indicated **a potential difference between Kaguya and the Moon of ~440 V**.

# Effect of Varying Plasma Conditions

**White Crosses**:
ISEE-3 data.

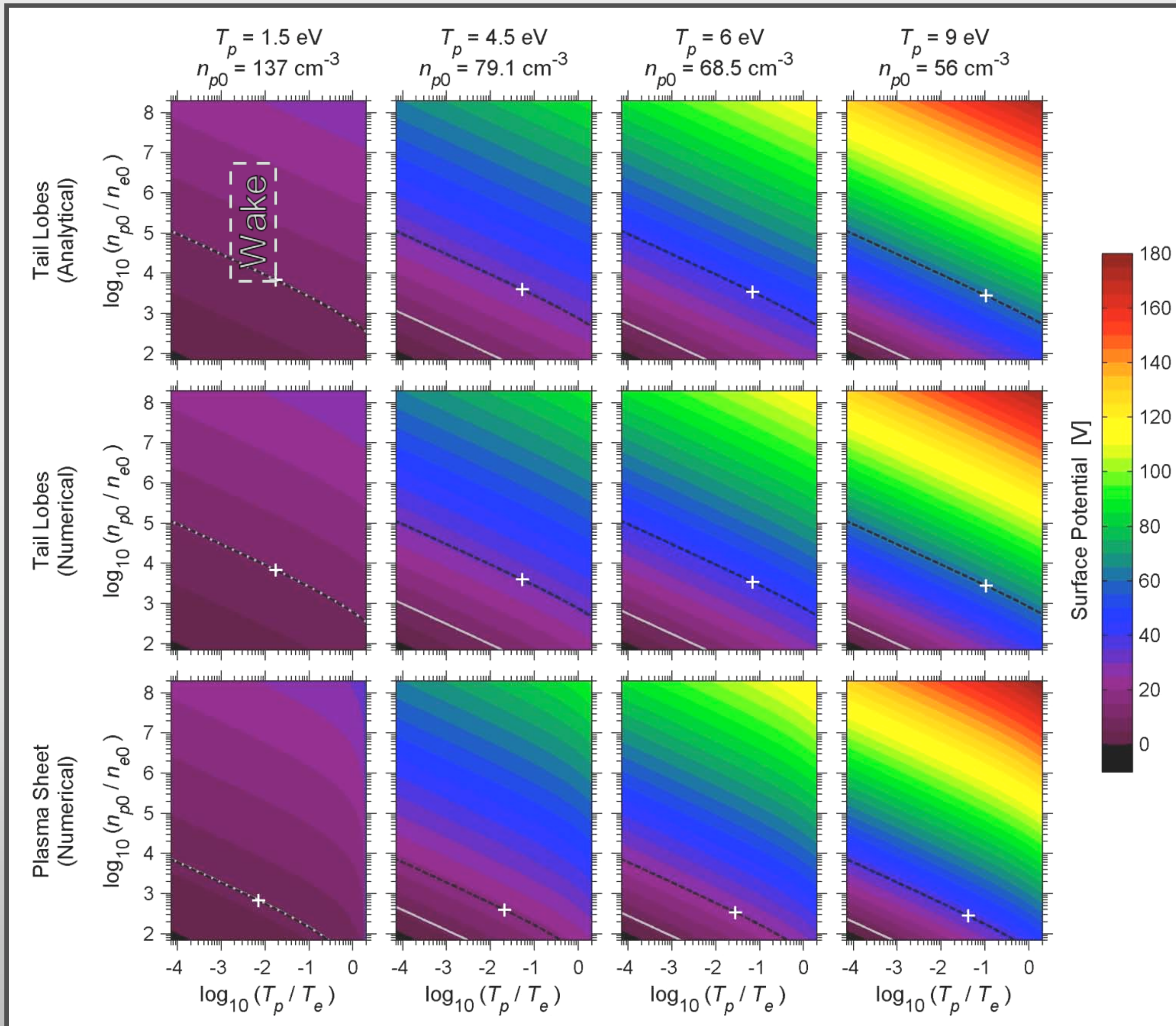
**Gray Lines**:
ISEE-3 prediction contours for $T_p$ = 1.5 eV (expected).

**Dashed Black Lines**: ISEE-3 prediction contours for various $T_p$.

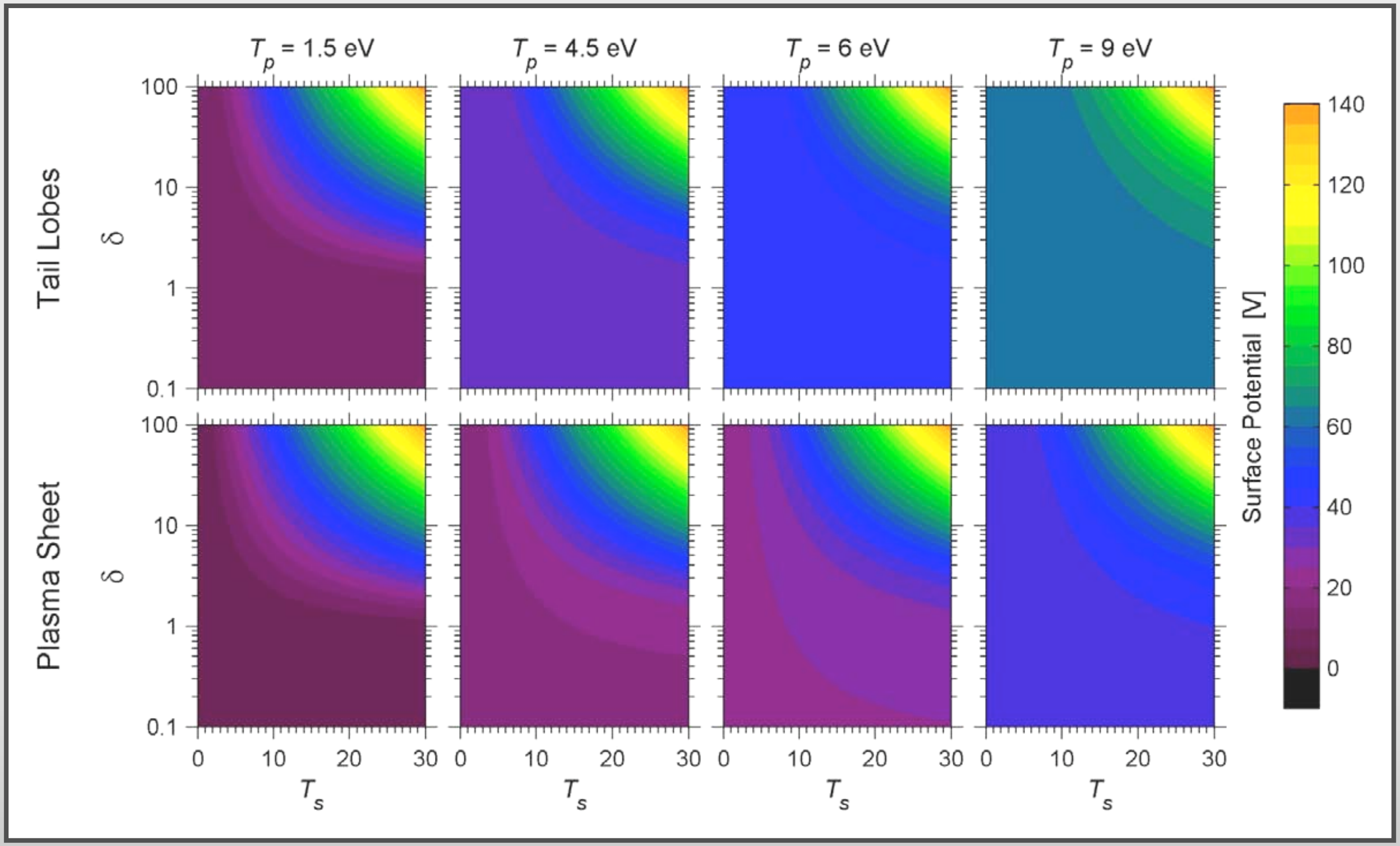
**Dashed Box**:
Possible Wake Perturbation from a Supersonic Earthward Flow.

~10 increase in $T_e$

~$10^3$ decrease in $n_{e0}$



# Effect of Varying Secondary Emission




**δ = secondary electron yield = $-J_s / J_e$.**

**Expect δ ~ 0 – 2 and $T_s$ ~ 3 eV.**

# Effect of Varying Both Plasma Conditions and Secondary Emission …

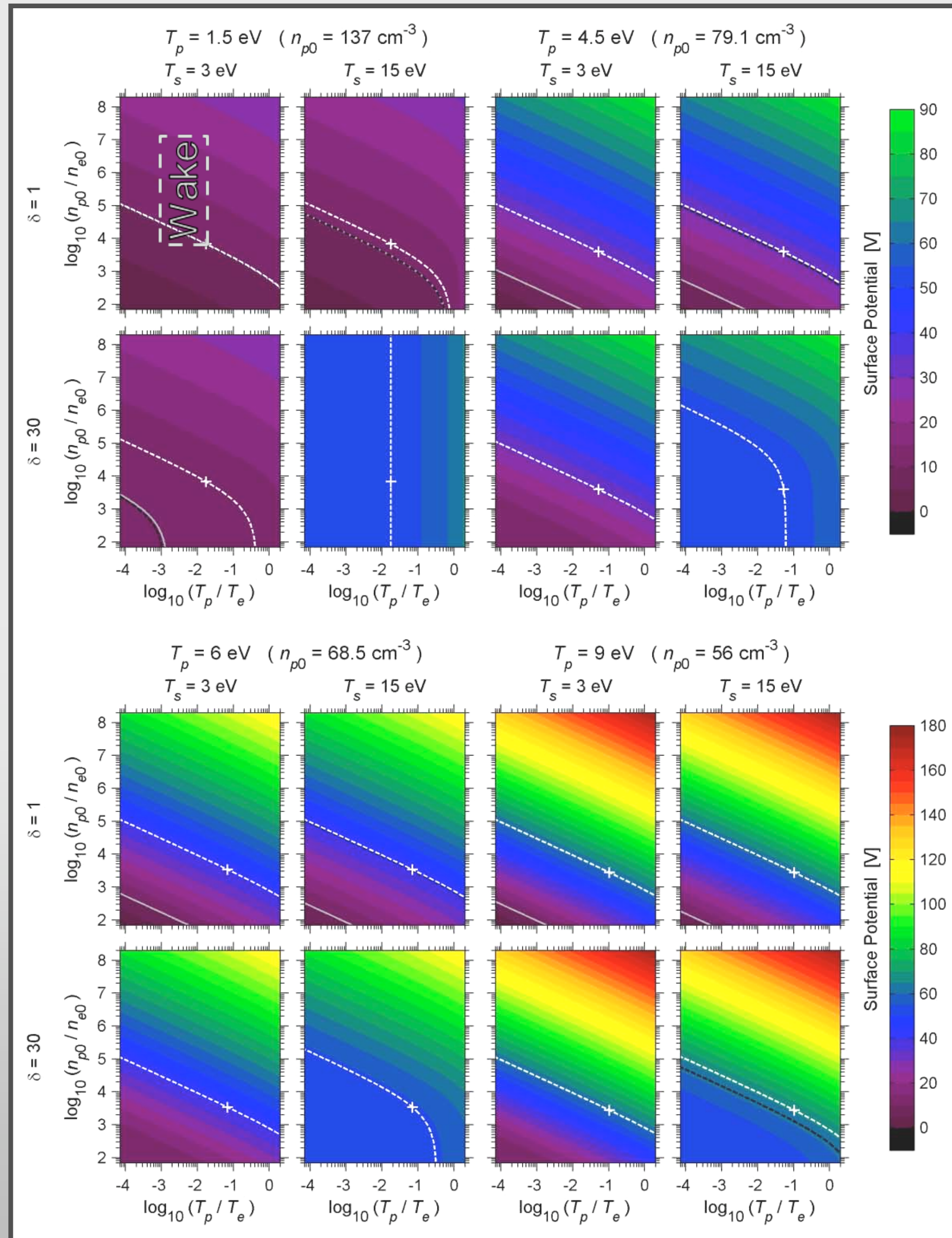
**White Crosses**: ISEE-3 data.

**Gray Lines**: ISEE-3 prediction contours for $T_p$ = 1.5 eV.

**Dashed Black Lines**: ISEE-3 prediction contours for $T_p$.

**Dashed White Lines**: ISEE-3 prediction contours for $T_p$, $T_s$ & $\delta$.

**Dashed Box**: Possible Wake Perturbation from Supersonic Earthward Flow.



# Summary and Conclusions

In order to achieve **extreme positive potentials of ~200 V** on the lunar dayside while in the tail lobes requires a combination of:

• **Much higher photoelectron temperatures** than expected

• **Excessively high secondary emission yields & temperatures**

• **A wake formed by a supersonic Earthward flow**

If this were the case, then similar extreme positive charging should be observed when the Moon is in the plasma sheet …?

Possible that the CPLEE data was **mis-interpreted** and the 200 eV electrons were not photoelectrons returning to the surface?

The potential difference inferred from the Kaguya could be due to a wake ambipolar potential (supersonic Earthward flow) and/or "lunar shadowing" effect [see Fillingim poster], **or something else …?**

# The Charged Particle Lunar Environment Experiment (CPLEE)

CPLEE deployed by Apollo 14 – measured ions and electrons with energies between 40 eV and 50 keV.

Reasoner and Burke [1972] suggested that CPLEE detected photoelectrons with energies of up to 200 eV on the dayside during passages through the tail lobes.

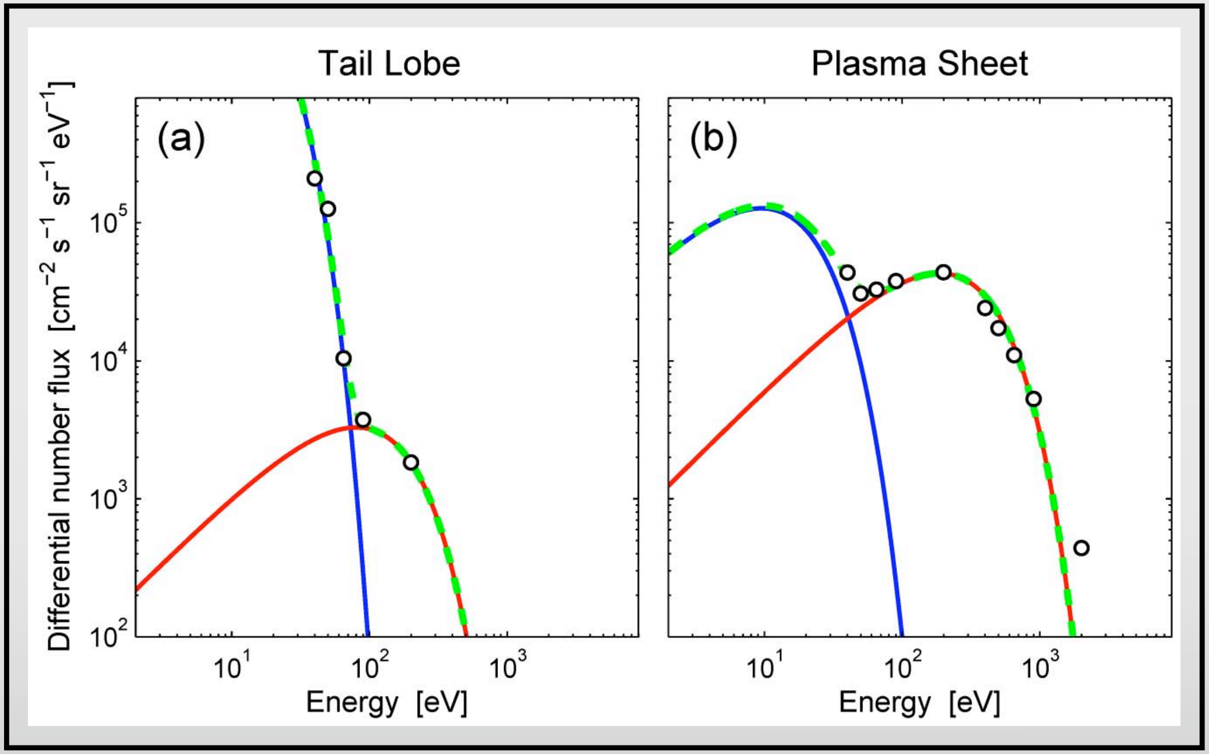
**It was argued that this was evidence for surface potentials of at least 200 V positive**!

This is **not consistent** with our predictions!

The 2 CPLEE detectors observed an **isotropic distribution**.

CPLEE at same potential as the Moon's surface … *possibly*.

# Preliminary Re-analysis of the CPLEE Electron Measurements in the Magnetotail




CPLEE measurements (black circles) fitted using two spectra based on Maxwellian distribution functions (green dashed lines) –

Hot (red lines) and cold (blue lines) components.

# The Source of these CPLEE Electrons …?

| Condition | $n$ cold [cm$^{-3}$] | $T_e$ cold [eV] | $n$ hot [cm$^{-3}$] | $T_e$ hot [eV] | $\phi_S$ [V] |
|---|---|---|---|---|---|
| Tail lobes | 10.3 | 6.5 | 0.015 | 80 | 0 |
| Plasma sheet | 0.2 | 9.5 | 0.3 | 187 | 0 |

These results assume that the electrons are from the ambient environment, as opposed to having originated from the surface.

**The derived $T_e$ are independent of the assumed $\phi_S$; whereas the *n* can be highly dependent on this assumption.** The higher the assumed $\phi_S$, the lower the *n* required to reproduce the observed spectra. In these cases, "*n* hot" is relatively insensitive over the likely range of $\phi_S$, whereas "*n* cold" can vary over orders-of-magnitude.

From a comparison with Table 1, **the hot components are clearly due to the ambient magnetotail plasma environment**.

# Summary and Conclusions

The CPLEE re-analysis indicates a bi-Maxwellian electron distribution at the dayside lunar surface while in the tail lobes and plasma sheet.

**In both cases, the hot component is almost certainly from the ambient magnetotail plasma environment.**

**The source of the cold component is less clear**. One possibility is the local lunar environment (e.g., the lunar ionosphere), while another is the positively charged surface (e.g., photo or secondary emission).

However, in order to fit the measurements in the tail lobe, the latter source would require a surface potential of **~ 100 V positive** and concentration at the surface of **~ $10^7$ cm$^{-3}$** – neither of which seems very likely.

**Therefore, our initial findings suggest that the CPLEE tail lobe measurements were due to the ambient space plasma (hot component) and possibly the lunar ionosphere (cold component), if the surface potential is ~ 10 V; as opposed to photoelectrons from the surface attracted back by a potential of > ~ 200 V.**